

# Appendix

Some of the works in this thesis have been presented as below:

- Wong, Y.Y. and Low, K.S., 2002. Verification and Enhancement of the Oil Spill Trajectory Model OILTRAJ for the Straits of Malacca. *In* Tropical Marine Environment: Charting Strategies for the Millennium. F.M. Yussoff, M. Shariff, H.M. Ibrahim, S.G. Tan & S.Y. Tai (eds). Malacca Straits Research and Development Centre (MASDEC), University Putra Malaysia, Serdang, Malaysia. pp. 823-832.

## **Verification and enhancement of oil spill trajectory model OILTRAJ for the Straits of Malacca**

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WONG, Y.Y. and K.S. LOW. 2002. Verification and enhancement of oil spill trajectory model OILTRAJ for the Straits of Malacca. *In Tropical Marine Environment: Charting Strategies for the Millennium*. F.M. Yusoff, M. Shariff, H.M. Ibrahim, S.G. Tan & S.Y. Tai (eds.), pp. 823-832. Malacca Straits Research and Development Centre (MASDEC), Universiti Putra Malaysia, Serdang, Malaysia.

### **Abstract**

The availability of an accurate oil spill trajectory model during oil combat operation will definitely help to minimize environmental damage following an oil spill. In this study, the existing oil spill trajectory model OILTRAJ for the Straits of Malacca is reviewed and its reliability improved. Important drift components that have been considered included the wind induced drift current, the tidal current and the background surface current.

The model has been verified with results from oil spill incidents (in the Straits) for the case of Nagasaki Spirit in 1994, the Eovoikos in 1997 and also the recent spill incident of Sun Vista in 1999. The results had shown generally good agreement in the long-term drift direction (more than 12 h) in the Straits and thus indicated the reliability of the model. However, the 2 dimensional tidal model failed to provide good results in the short-term drift (less than 12 h) for near coastal zones. In these cases, the semi-diurnal tidal currents have played important roles in the long shore drifting of the oil slick and the discrepancies have shown the numerical artifact of the 2-D tidal model at the near coastal zone due to finite numerical grid points in the numerical model.

Since the Straits of Malacca is a long narrow channel, a more reliable 1 dimensional tidal model could therefore be used to replace the 2 dimensional model. Results of 2 field tests on drifting objects off the coasts of Melaka and Pangkor have been used to verify the tidal model. In these cases, the basically long shore tidal current from the 1-D model together with the wind induced drift and background surface current have provided good agreement in both magnitude and direction with the experimental data. It has been clearly shown that the OILTRAJ program together with the 1-D tidal model could appropriately reproduce the oil slick trajectory in the Straits of Malacca for both short and long term drifting periods.

### **Introduction**

An average of 32,331 vessels use the Straits of Malacca yearly (Marine Department, 1997) of which 34% are oil tankers. The high frequency usage of the narrow shipping lane is associated with high risks and occurrence of marine pollution. Accidental and

operational discharges of oil pollutants from shipping vessels plying the Straits being the primary threat of oil spills. This has received particular concern over the past years by scientists and governments from the three littoral states of Indonesia, Singapore and Malaysia.

Regardless of the spill reasons, the rich marine and coastal resources in this relatively congested channel are exposed to high risk of pollution and degradation. An accurate oil spill trajectory model is therefore an essential tool in the combat of oil pollution for the sustainable management of the Straits. In this study, the existing oil spill trajectory model OILTRAJ developed for the Straits of Malacca was reviewed. Modifications were carried out in order to enhance its capabilities for both short-term as well as long-term prediction.

### Oil Spill Trajectory Model OILTRAJ

Based on the methods suggested by Haug *et al.* (1990), an oil spill trajectory model (OILTRAJ) for the Straits of Malacca had been developed for the Malaysian Department of Environment (Low *et al.*, 1994). In that model, various drifting components that have been taken into considerations were as follows:

1. Wind induced drift current for oil on the sea surface.
2. Tidal current.
3. Surface current

Computation of the oil spill trajectory can be described by the following equation:

$$r(t) = r(t_0) + \int_{t_0}^t U(t)dt$$

where  $r(t)$  is the vector coordinate of a slick at time  $t$  after its initial spillage at time  $t_0$ .  $U(t)$ , is the propagation velocity of the slick which is equal to the vector sum of the various surface drifting components:

These surface drifting components included the current set up by wind ( $U_{wind}$ ), which also included the effect of land-sea breeze, the tidal current ( $U_{tides}$ ), and the residual

$$U(t) = \alpha U_{wind}(t) + U_{tides}(t) + U_{current}(t)$$

background current ( $U_{current}$ ). As suggested by Haug *et al.* (1990), the wind induced current is approximately 3% of the wind velocity near the equator. A value of  $\alpha = 0.03$  is therefore used for wind induced current for oil on the sea surface.

For the oil spill trajectory calculation, wind data can be obtained from measured/forecast wind velocities over the spilled areas, or retrieved from stored data of synoptic wind for the Straits. Near to the coastal areas, the effects of the land-sea breeze were

also taken into consideration. A 1-D land-sea breeze model had been developed by Lim and Yeong (1992) for this purpose.

In the Straits of Malacca, a 2 dimensional tidal model developed at the University of Malaya was incorporated into the oil spill trajectory model (Lee, 1994). The tidal data used in the OILTRAJ was calculated using the  $M_2$  and  $S_2$  tidal components. The phases and amplitudes of the tidal information were generated and stored in matrix form. It could be retrieved and interpolated to obtain the tidal current when needed. Tidal current could be calculated for any time and location along the Straits by using a lunar calendar incorporated into the model.

The hydrographic feature of the Straits of Malacca is highly influenced by adjacent oceans. Surface current in the Straits is generated as a resultant interplay of oceanic currents and weather conditions in the Indian Ocean and the South China Sea. The current flows mainly in two directions for both monsoon seasons and depend on the sea level difference between the southeast and northwest entrances (Wyrski, 1961). The dominant direction is northwestward from the southeast entrance (from South China Sea) to the northwest entrance (to Andaman Sea). Another surface current enters the Straits of Malacca from its northwest entrance (Andaman Sea) with a southeasterly flow, but reverses itself to the northwest direction near the waters off the northern end Peninsular Malaysia. Although the change in monsoons does not appear to influence the direction of flow, it influences the amplitude and velocity of the surface current. Thus, the flow of the surface current is stronger during the northeast monsoon, when stronger winds prevail, than the southwest monsoon. Data as compiled in the Naga Report (Wyrski, 1961) has been digitized for the application in the Straits of Malacca.

The model was verified with results from a number of major oil spill events in the Straits, e.g. the Nagasaki Spirit in 1994 and the Evoikos in 1997. The oil slicks from these spill incidents (which spilled 13000 t of crude oil and 25000 t of heavy fuel for the cases of Nagasaki Spirit and the Evoikos respectively) drifted on the sea surface for more than a week. Due to a lack of detailed observation data of oil slick motion, simulation of the Nagasaki Spirit oil spill trajectory using OILTRAJ had shown only qualitatively agreement with the observed data (Low *et al.*, 1994). In the case of Evoikos, simulation could not be reliably calculated due to a lack of information on oil combat operation that had been carried out in the early stages of the spillage. Nevertheless, both results computed from the model did indicate some reliability of the model in forecasting the long-term drift (more than 12 h) and its usefulness in determining oil spill movement. In both cases, tidal current did not play a significant role in the long-term drift of the oil slick.

An accurate oil spill trajectory model however should also be able to perform equally good short-term prediction (less than 12 h). This is especially important during the oil combat operation because of the relatively rapid changing direction of the water movement dominated by the tidal effect. The original OILTRAJ model was unable to show this capability after it failed to reproduce the trajectory of drift objects in two field tests conducted near the coast in the Straits. The semi-diurnal tidal currents have played



important roles in the long shore drifting of floating objects in the field tests. The 2-D tidal model was used to calculate the tidal current along the Straits and it clearly showed that this model could not provide a reasonable prediction for both near-coast tidal effects. The discrepancies in direction became rather significant with increasing time. The poor prediction near land masses might be due to inadequate resolution in the 2-D modeling of the coastline and bottom geometry (Low *et al.*, 1994).

Since the Straits of Malacca is a long narrow channel, the 1 dimensional tidal model is believed to be more reliable to reproduce the tidal movement especially near coastal zones. In this study, the 1-D tidal model developed at the University of Malaya (Lee, 1994) was used to generate the tidal currents along the Straits.

Earlier studies carried out by Lee (1994) showed that the tides along the Straits could be equally well represented by the 1-dimensional and 2-dimensional models. Both models provide rather similar results especially in the middle of the Straits. However, modeling failure is believed to have occurred in the 2-D model, mainly in the prediction of tidal current near the shoreline. On the other hand, the 1-D model is known to be sufficient because the tidal current along the Straits of Malacca can be well represented by a simple one directional water movement due to its relatively long and narrow nature. Furthermore, only minimum computation resources are required in the 1-D model and much simpler programming is involved during the construction of the model.

For the 1-D model, the Straits is thus regarded as a long irregular channel that has been subdivided into numerous sections of which the length of the sections chosen are small compared to the wavelength of the tidal components. Four tidal components, i.e.  $M_2$ ,  $S_2$ ,  $K_1$ ,  $O_1$  have been included in the tidal calculation. These four separately calculated components would be superimposed to obtain the tidal elevations and currents of any particular point along the Straits for any time.

### Field Tests and Verification Study

Two field tests were carried out in the Straits of Malacca in 1993, off the coast of Melaka and Pangkor, on 22<sup>nd</sup> of August and 27<sup>th</sup> of August respectively (Low *et al.*, 1994). For the field tests, a crate each of oranges and apples were used as tracer particles and were thrown into the sea which has an average depth of 30 m, and tracked at a visible distance away on a boat. The mean trajectory of the fruits was recorded using a global positioning system (GPS)- Sony model IPS-360, at every 15 min interval, for about 4 h. The wind speed was determined using a wind anemometer and the direction with a wind sock.

Fruits were used to represent crude oil on the sea, as the spillage of hydrocarbon into the sea is not environmentally permissible. However, this was sufficient to investigate the transportation of the oil slick on the sea surface under various drifting mechanisms. The fruits used in the tests have an average density of approximately  $0.8 \text{ kg m}^{-3}$ .

which was almost similar to that of oil. However, these floating fruits with about 20% of its volume above the surface exposed to the air will be subjected to a greater wind stress and resulting in a larger wind induced velocity. Therefore, a higher value of wind induced current was used in the computation of the trajectory of the floating fruits. Together with the wind induced current and the surface current, 1-D tidal model was used to generate the result for the field tests.

Field test results are shown in Figure 1 (for Melaka test) and Figure 2 (for Pangkor test). In both tests, the 3 drift components i.e. wind induced current, tidal current and surface currents were calculated at each time step. Different values for wind induced velocity have been used in order to investigate the wind factor in the experiments.

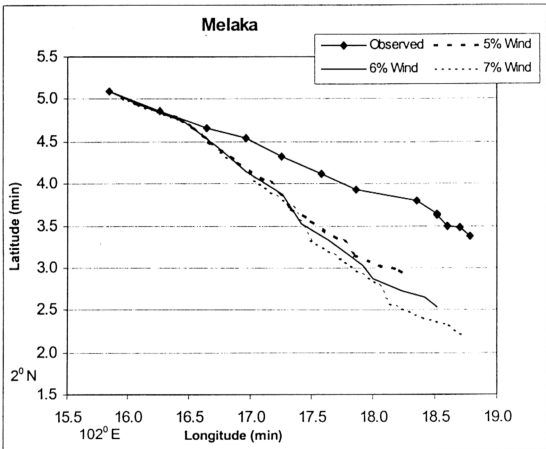


Fig. 1. Comparison of observed location of drifting fruits off Melaka and computed result using 5, 6 and 7% of wind velocity.

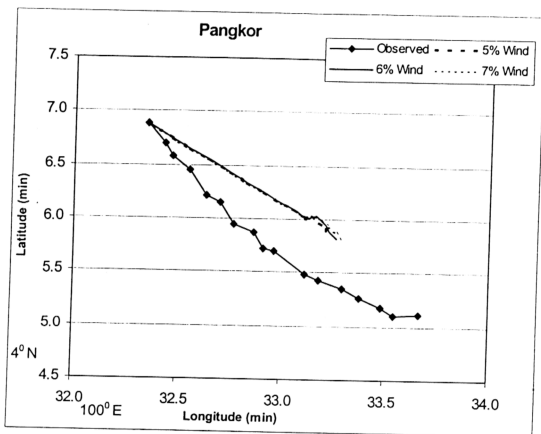


Fig. 2. Comparison of observed location of drifting fruits off Pangkor and computed result using 5, 6 and 7% of wind velocity.

In the experiments, real-time wind data were used. The wind conditions during the Melaka test varied from 5 to 16 knots, with a mean of 13.8 knots from the directions between  $310^{\circ}$  to  $360^{\circ}$ . Under this strong wind circumstance, it is an ideal case to examine the wind induced velocity. It is shown that the 6% wind induced velocity give the best results. In the case of Pangkor where there are no winds observed for the first 3 h of the experiment, and therefore the results showed no significant different when the wind factor is changed as for case of Melaka. However, in this calm condition, the tidal current played important role to drive the slick movement.

The tidal current gave a remarkable effect in the short-term prediction during these 2 field tests. Generally good agreement was achieved as shown in the figures above. Tidal currents generated by the 1-D model showed the correct magnitudes and directions especially for the Melaka test.

Another important component used in these tests is the surface currents. During the experiments, the surface current for the month of August off the Melaka has a velocity

of  $0.25 \text{ m s}^{-1}$  to the direction of  $320^\circ$ , which was rather similar to that of the combined wind and tidal generated currents but in the opposite direction. After the 3 h test, the surface current had drifted the fruits in the backwards direction for a distance of about 2700 m. For the Pangkor test, a slower current with about  $0.12 \text{ m s}^{-1}$  to the direction of  $140^\circ$  has been applied. This however has greatly improved the result of the prediction by drifting the fruits for more than 1700 m after 4 h in the experiment.

Tidal effect was taken into consideration in OILTRAJ model although the tidal current might not play a significant role in the long-term drifting of oil slick due to its oscillatory nature. However, tidal current was considered in the short-term prediction because of its fast changing directional behaviour. Moreover, in the narrow Straits of Malacca, tidal current could reach a considerable strength. For instance, a pure tidal generated current at the One Fathom Bank could reach up to a velocity of  $0.52 \text{ m s}^{-1}$ . Within 6 h or half a tidal cycle, an oil slick could be drifted by more than 8.3 km. An accurate tidal model was therefore necessary during the oil booming and cleaning operation and the 1-D tidal model could assist in this matter.

Some discrepancies were observed in both field tests. In the Melaka case, the magnitude of the drifted mechanism seemed to be well reproduced using the model. The phases and magnitudes of each component used in the tidal model were correct, and so was the case for surface current. Errors in directions were most probably caused by inaccuracy of the mean direction chosen for the surface current. However, that could not be further investigated due to a lack of accurate measured data for surface currents. The available data for surface currents were obtained from the average velocities in the most frequent direction over a wide area (Wyrki, 1961). For the case of Pangkor test, the same discussion can be applied on the direction of the drift components. Furthermore, in this case, the magnitudes of the current vectors were also underestimated. These may be due to the inaccurate vector chosen for the surface current at the appropriate location. Updated and better surface currents data are necessary for the development of a high accuracy oil spill model.

### **Oil Spillage of Sun Vista**

To ensure that the model is applicable in the Straits of Malacca, further verification was carried out with a recent oil spill incident of the Sun Vista. On 21<sup>st</sup> May 1999, a cruise liner Sun Vista, which caught fire in the engine room, sank off Pangkor Island, and spilled diesel oil from its fuel tank. The cruise liner sank at 1.22 a.m. at about 80 km from the shore ( $4^\circ 36' \text{ N}$ ,  $99^\circ 52' \text{ E}$ ) and a spillage of 2100 t of its fuel oil has been reported.

In the computation of the oil spill trajectory (based on the information provided by DoE), it was assumed that the oil started leaking out at 3.00 a.m. at a rate of  $10 \text{ t h}^{-1}$ . The hourly wind data obtained from the Malaysian Meteorological Service was been used during the simulation of oil slick trajectory. Three percent of the wind induced current was used. The effect of land-sea breeze was taken into account when the

slick was near to the coast. As discussed above, the more reliable 1-dimensional tidal model was used to calculate the tidal motion. Surface current data for the appropriate month was employed as one of the drift components.

Aerial surveillance of the oil slick was started on the fifth day after the oil spillage. During the spillage, no oil landed on the coast but had drifted as a long narrow oil slick northwesterly all the time. The prediction of oil slick trajectory was computed hourly. Some of the oil slick trajectory computation results were displayed and compared to the observed data as reported by DOE and are shown in the Figure 3.

The results from the Sun Vista incident showed that the model is able to predict the trajectory of an oil spill on the sea. Good agreement between the computed and observed oil slick showed that the model is reliable to be applied for oil spill trajectory prediction in the Straits of Malacca.

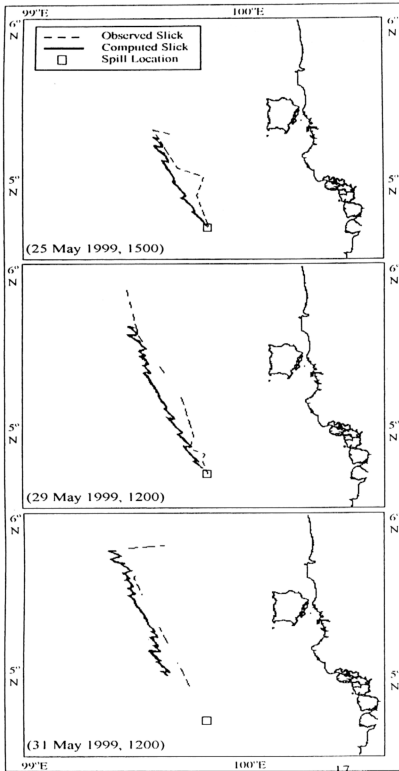
From observed data of the spillage, the oil slick finally became small isolated patches of sheen on its track. The spilled fuel oil, which had a high volatility in character, was believed to have evaporated and dispersed after a few days, especially during the mid-year hot and dry season. The weathering process was assumed not to alter the oil slick trajectory on the surface. In fact, the drifting components would affect the weathering processes. For instance, the wind stress on the surface would help to spread the oil and also break up the slick. However, the interaction between the surface drifting current and the weathering processes was not investigated in this paper.

### **Discussion and Conclusions**

The reliability of OILTRAJ model as well as the validity of its oil slick trajectory drifting components were verified in this paper. The propagation of the oil slick trajectory on the sea surface was calculated using 3 main drifting components, i.e. the wind induced current, surface current and tidal current. These components have been verified with two field test results as well as the Sun Vista spill event. Generally good results obtained in the spill events indicated the reliability of OILTRAJ in oil slick trajectory calculation in the Straits of Malacca.

A simple and reliable 1-D tidal model was incorporated into the OILTAJ model in order to enhance its capability in short-term prediction and as an important tool to predict the water movement during the oil booming and cleaning operation. 1-D model replaced the 2-D model because minimum resources were required and was more reliable in the coastal zones. The reliability of the 1-D model was verified in the field tests.

Surface current is another important component that should be considered. In the Straits of Malacca, surface current is a relatively constant flow throughout the year. More accurate data on surface current will have to be obtained for a better prediction. This



Note: The observed slicks are reproduced from the Department of Environment data.

**Fig. 3.** Comparison of oil spill trajectory modeling results for Sun Vista incident.

background current will likely determine the propagation of the oil slick especially during slow wind condition. Together with the synoptic wind data, an effective long-term oil spill contingency planning could be made.

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